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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: September 30, 1975

Project Title: Development of a Solar Heat Supply System With Fixed Mirror Concentrators

Project No: E-25-659

Principal Investigator Dr. J. R. Williams

Sponsor: Energy Research & Development Admin., Oak Ridge Operations, Oak Ridge, Tenn. 37830

Agreement Period: From 7/1/75 Until 6/30/76

Type Agreement: Contract No. E(40-1)-4970

Amount: $157,386 ERDA Funds
3,475 GIT Contribution
$160,861 Total Estimated Cost

Reports Required:

Publication Preprints; Publication Reprints; Annual Progress Report; Final Report.

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Assigned to: Mechanical Engineering

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SPONSORED PROJECT TERMINATION

Date: 12/4/78

Project Title: Development of a Solar Heat Supply System with Fixed Mirror Concentrators

Project No: E-25-659

Project Director: Dr. J. R. Williams

Sponsor: Energy Research & Development Admin., Oak Ridge Operations

Effective Termination Date: 7/31/77

Clearance of Accounting Charges: 7/31/77

Grant/Contract Closeout Actions Remaining:

- X Final Invoice ~~and Closing Documents~~
- X Final ~~Fiscal Report~~ Certified Statement of Costs
- X Final Report of Inventions - ART B - VIII covers all except GFP
- X Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______________

Assigned to: Mechanical Engineering (School/Laboratory)

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E-25-659

DEVELOPMENT OF A SOLAR HEAT SUPPLY SYSTEM

WITH FIXED MIRROR CONCENTRATORS

ERDA CONTRACT NO. E(40-1)-4970

by

J. Richard Williams
Samuel V. Shelton

FINAL REPORT

DEVELOPMENT OF A SOLAR HEAT SUPPLY
SYSTEM WITH FIXED MIRROR CONCENTRATORS

ERDA Contract No. E(40-1)-4970

Program Manager: Dr. Steven L. Sargent

Work Performed By

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ABSTRACT

This report summarizes the accomplishments under ERDA Contract E-(40-1)-4072 of a program of continued development of a solar heat supply system employing a faceted fixed mirror concentrator (FFMC). This concentrator has provided heated air at several hundred degrees Celcius with efficiency exceeding conventional collectors. Under this contract the prototype FFMC was fitted with a liquid-heating receiver which employes evacuated tubular collectors of high efficiency.

The new contract, ERDA No. E-(40-1)-4972, was initiated in March 1976 with a subcontract to Scientific-Atlanta to: 1) fit the concentrator with a receiver using a selective absorbing surface and a liquid collecting medium, 2) to develop a mechanical design based on mass production manufacturing techniques, 3) develop cost estimates to produce this design, and 4) predict annual performance of the resulting collector. These items will be discussed in sequence in the following sections.

INTRODUCTION

This program is a continued effort to develop and evaluate a solar heat supply system capable of supplying heated fluid at high temperatures. The objective is the design, construction and testing of a fixed mirror solar concentrator with moving sun-tracking receiver capable of supplying heat economically at temperatures in excess of 250 °C (482 °F). At these temperatures, standard flat-plate collectors are essentially ineffective while conventional focusing collectors capable of achieving such temperatures required precise optical components and an extensive structure and mechanism to provide for moving the entire concentrator to follow the sun. The faceted fixed-mirror concentrator developed in this program circumvents the shortcomings of previous collector systems and promises to provide a means of satisfying a significant fraction of the energy needs of an advanced economy.

The faceted fixed-mirror concentrator (FFMC), Figure 1, as proposed by Russel (1) and described in previous publications relating to earlier work in this program (2 and 3) requires no movement of the concentrator mirror and can be constructed using low cost commercially available rear-surfaced mirrors. The FFMC consists of an array of flat elongated mirror slats arranged on a concave circular cylindrical surface. As shown in (1) and (4) the prescribed arrangements of mirror slats results in a concentrator having a non-imaging focus always falling on the surface of the generating cylinder. This design avoids the severe off-axis aberation characteristic of moving collector systems employing spherical (5) or parabolic (6 and 7) fixed concentrators. Since the sunlight is focused sharply along a line of the generating circular cylinder, the moving collector need only be carried through a circular motion while tracking the sun. This motion can be provided by a simple pivoting arm augmented by a four bar mechanism to maintain the collector and terminal concentrator in alignment with the focused sunlight. No extensive structure and mechanism capable of supporting and moving the massive mirror array is needed to provide effective collection of the incident radiation. A closed-loop controller employing a photocell detector is used to position the moving collector.

The FFMC is capable of meeting a variety of energy needs. In the configuration under development during this program, the moderate (around 20:1) concentration ratio will allow efficient collection of heat at temperatures in excess of 250 °C (482 °F). Since conventional flat-plate collectors are inefficient at plate temperatures above 100 °C, such collectors are practical only for low-temperature applications such as providing domestic hot water and space heating. Flat-plate collectors have limited applicability even for driving absorption-cycle refrigeration systems since a typical refrigerant-solvent pair such as water-LiBr requires collection at temperatures near the practical maximum (around 80 °C (176 °F)) for efficient steam generation. The ability to provide heat at temperatures above 250 °C opens wide areas of application to the FFMC. Industrial process heat and steam can be provided directly. The FFMC can be used to drive organic-fluid Rankine cycle converters for electrical and direct-drive power, or power and heat can be provided in a total energy system. Used as augmentation to a conventional heat pump, the FFMC will provide dramatically improved performance. The high temperatures will also allow for enhanced COP when used in absorption refrigeration cycles. The promise

Accomplishments

During this project we have worked to identify the causes of limited performance of the original air-heating FFMC prototype, to design and construct an improved prototype using evacuated tubular collectors in an oil-heating receiver, and to proceed with the design of a commercially-viable FFMC design based on the experience gained from extensive operation of the 50.17 m^2 (540 ft^2) FFMC collector. Additionally, analytical work has been completed to predict the operational efficiency of the FFMC under various conditions of solar position, insolation, and fluid collection temperatures. Extensive experimental operation of the FFMC with air-heating receiver has been completed. Tests were accomplished to evaluate the performance of the oil-heating receiver and the numerical model for the collector.

The experimental work performed with the air-heating FFMC has shown that poor overall efficiency results because of poor thermal efficiency of the air-heating receiver and the excessive pumping power required to force a large volume of air thru the heat collector. Inspection of Figure I demonstrates that, although increased air flow thru the collector raises the collection efficiency, the increase in blower power is steeper. A useful illustration of the performance of a solar collector is the plot of solar energy against the operational parameter, $(T_f - T_a)/I$, where T_f is the air exit temperatures, T_a = ambient temperature, and I is the direct solar insolation on the aperture plane of the collector. This parameter is important because, as determined in the classic paper by Hottel and Woertz (8), the efficiency of a flat plate collector approximates a linear function of the operational parameter with slope determined by the overall heat loss coefficient and intercept determined by the effective product of the cover transmittance and plate solar absorptance. A plot of the experimental results for the FFMC is shown in Figure II. For comparison, the efficiency from manufacturer's literature (9) for a typical air-heating flat plate collector is also shown. In both cases the efficiency is the quotient, Qu/IA, where Qu is the net useful heat gain rate, I is the insolation on the plane of the collector, and A is the collector area. As seen in the figure the efficiency of the FFMC greatly exceeds that of the flat plate collector at higher values of the operational parameter. This is a promising result, however, the FFMC can operate only with direct radiation while the conventional collector works about as well with diffuse insolation and the conventional collector is less expensive. To improve the economic advantage of the FFMC the overall collection efficiency must be improved. To improve the efficiency it is most important to reduce the losses by heat transfer and power consumption by the air blower. Toward this aim, the prototype has been modified by the installation of evacuated tubular collectors. This collector is used with Therminol-66 heat collection fluid.

The performance of the FFMC is degraded by the low optical efficiency of the initial design. The FFMC prototype has been provided with mirrors of low iron content for evaluation. These inexpensive sheet-process glass mirrors promise improved concentration efficiency due to their greater reflectivity while retaining acceptable surface quality.

Prototype Modifications and Design Improvements

A significant design change is the elimination of air as the heat transfer medium in favor of an organic oil. The favorable heat transport properties of the oil enhance the collection efficiency of the terminal receiver. A liquid heat transfer medium will also greatly reduce the pumping loss which has plagued the air-cooled collector. The low vapor pressure of the organic heat transfer oil is compatible with the thin-walled tubing welded to the absorber plate of the evacuated tubular collectors now installed to replace the air-heating receiver of the original design. The new collectors are Corning Tubular Evacuated Collectors (CTEC). Convective and conductive losses are suppressed by the hard vacuum within the collector which will allow operation at elevated absorber plate and coolant temperatures without degredation of efficiency. The evacuated collectors utilize high transmittance glass in the tubular envelope and a selective coating on the absorber plate. This combination of thin, 2.5 mm (0.1 inch), glass cover and selective black-chrome coated absorber will reduce optical and thermal radiative losses. Another design modification under development is the replacement of the existing float glass mirrors of 83% reflectivity with low iron sheet glass mirrors of 90% reflectivity.

In addition to the design improvements which will enhance the efficiency of the FFMC, several improvements have been designed to yield a more cost-effective design. A new design of the drive system for positioning the collector was completed. Replacement of the existing inefficient Acme screw jacks by ball-screw jacks, with anti-friction ball-bearing contact, allows the use of less expensive components throughout the sys-

1. Liquid Receiver Subsystem

A liquid receiver was designed utilizing 4-inch diameter, 8-feet long evacuated glass tubes containing a 0.010 inch copper absorber plate with a black chrome selective coating supplied by Corning Glass. The fluid passage was a single pass 5/16" copper tube seam welded to the absorber plate. The inlet and outlet was at one end with glass to metal vacuum seals.

These tubes were placed end-to-end along the focal line inside a terminal reflector with an Alzac reflecting surface. The aperture to the terminal reflector is 6 inches in width. Due to the necessarily rounded ends of the tubes and the inlet-outlets at the evacuated tube ends, the absorber plates could not be butted against each other resulting in 4% of the length along the focal line not being covered by an absorber plate. An end view of the configuration of the receiver and its attachment to the concentrator is shown in Figure 2.

The piping to circulate a Therminol 66 heat transfer fluid through the evacuated tubes connected in parallel is shown in Figure 3. A variable speed electric drive is attached to a constant displacement Viking pump. This pump receives fluid from a nitrogen pressurized (1 psig) 20 gallon storage tank pumping it through two Therminol-to-water heat exchangers and subsequently through the 10 receiver tubes connected in parallel.

The supply and return for the individual evacuated receiver tubes was via insulated supply and return manifolds running behind the terminal reflector as shown in Figure 2. These lines were 1" carbon steel with 1 inch of insulation on each tube. Additional insulation would cause shadowing of the primary reflector.

Rather than insulate each component of the fluid system, an insulated box was constructed and the pump, storage tank, filter, and heat exchangers were placed in the enclosed box. Water flow was measured and regulated

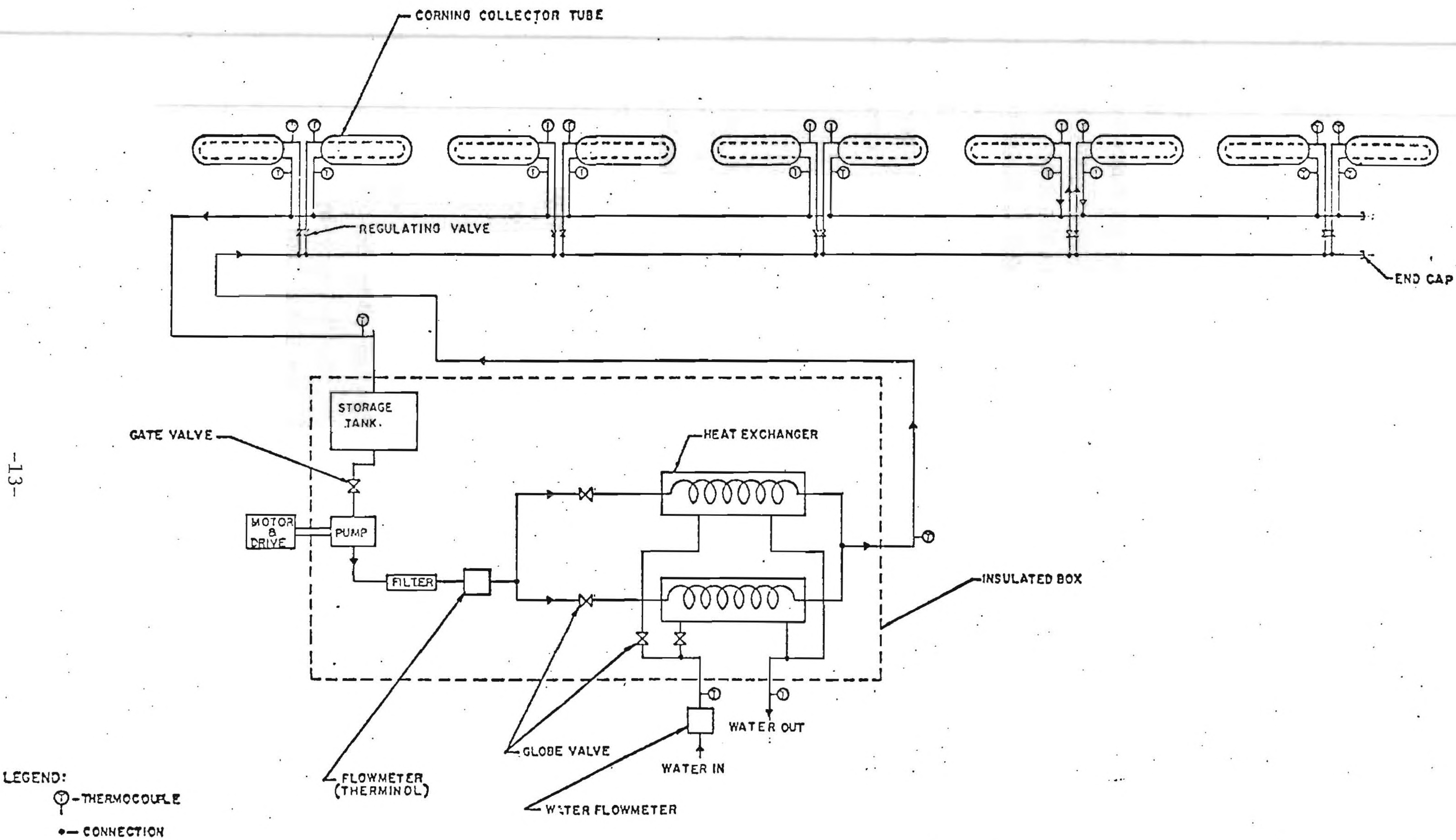


Figure 3. 540 ft^2 Concentrating Collector Fluid Flow Diagram

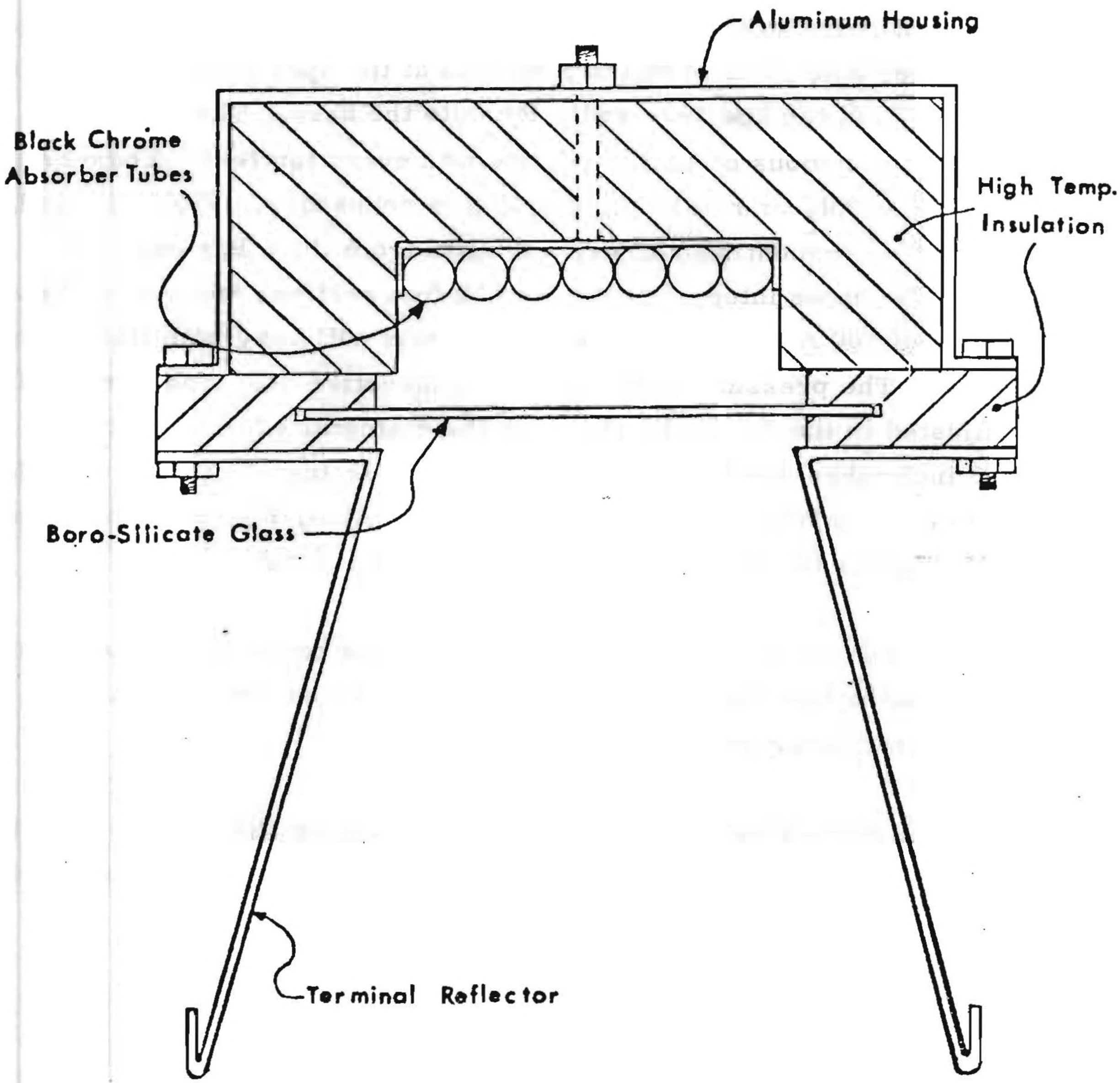


Figure 4. FFMC Receiver Configuration

HEAT LOSS FROM SCIENTIFIC-ATLANTA FFMC RECEIVER

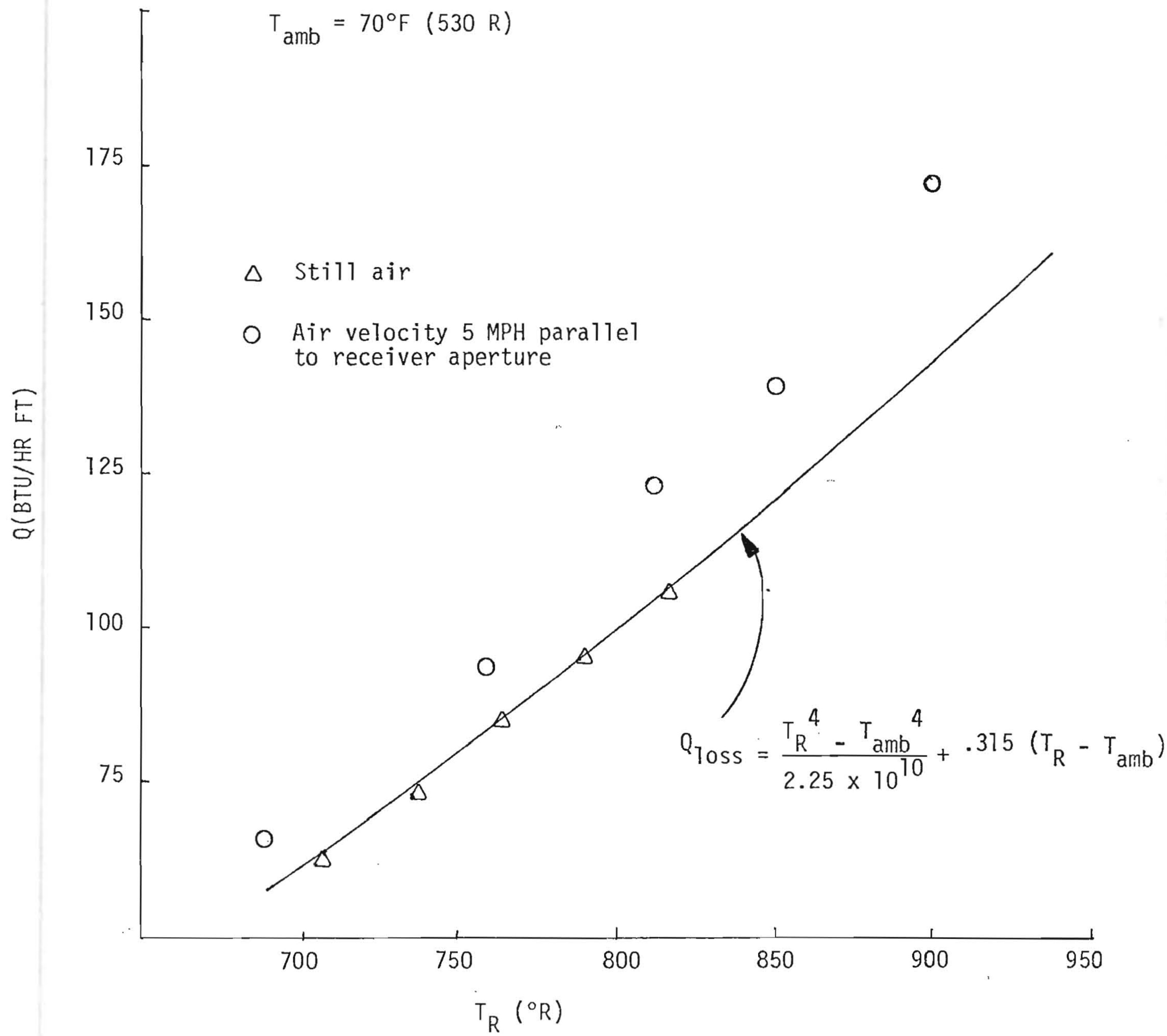


Figure III. Heat Loss Measurements and Comparison with Analytical Results

2. Mass Production Mechanical Design

The 540 ft^2 prototype designed and constructed by Scientific-Atlanta, Inc. was intended to be only a "one-off" unit. Under this present contract, the design of the FFMC was studied to determine how mass production techniques could be utilized and still maintain the necessary 1/8° standard deviation required on the 28 faceted mirror orientation. Die stamping was then selected as the manufacturing technique and a design developed to use that technique. Photographs showing a 10 foot module constructed from this design is shown in Figures 5 and 6.

The basic structural unit of the FFMC is made up of mirror support channels and channel support brackets. The mirror support channels are 5 feet long and are to be roll formed from galvanized steel. These are shown in Figure 7. The channel support bulkheads are placed every five feet, are made of galvanized sheet steel, and are used to support the ends of the mirror support channels. These are die stamped in two identical halves which can be bolted together. This die stamped piece is shown in Figure 8. Assembly of these pieces is shown in Figure 9.

Two channel support brackets and 56 mirror channel supports can be assembled to produce a repeatable 10 foot module with an aperture area of 67 ft^2. These 10 foot long modules can be assembled end to end in an east-west direction to make an array with a total aperture 6.7 feet wide by n X 10 feet long where n is any integer. One 1/4 HP motor driven jack per 130 ft long array is used to track the receiver. This drive and jack are shown in Figures 10 and 11.

The mounting pads for these modules and arrays consist of two pads for every five feet of east-west length. These two supports are approximately five feet apart in the north-south direction. The recommended mounting pads are six-inch diameter concrete posts with a threaded stud cast into the top of the post.

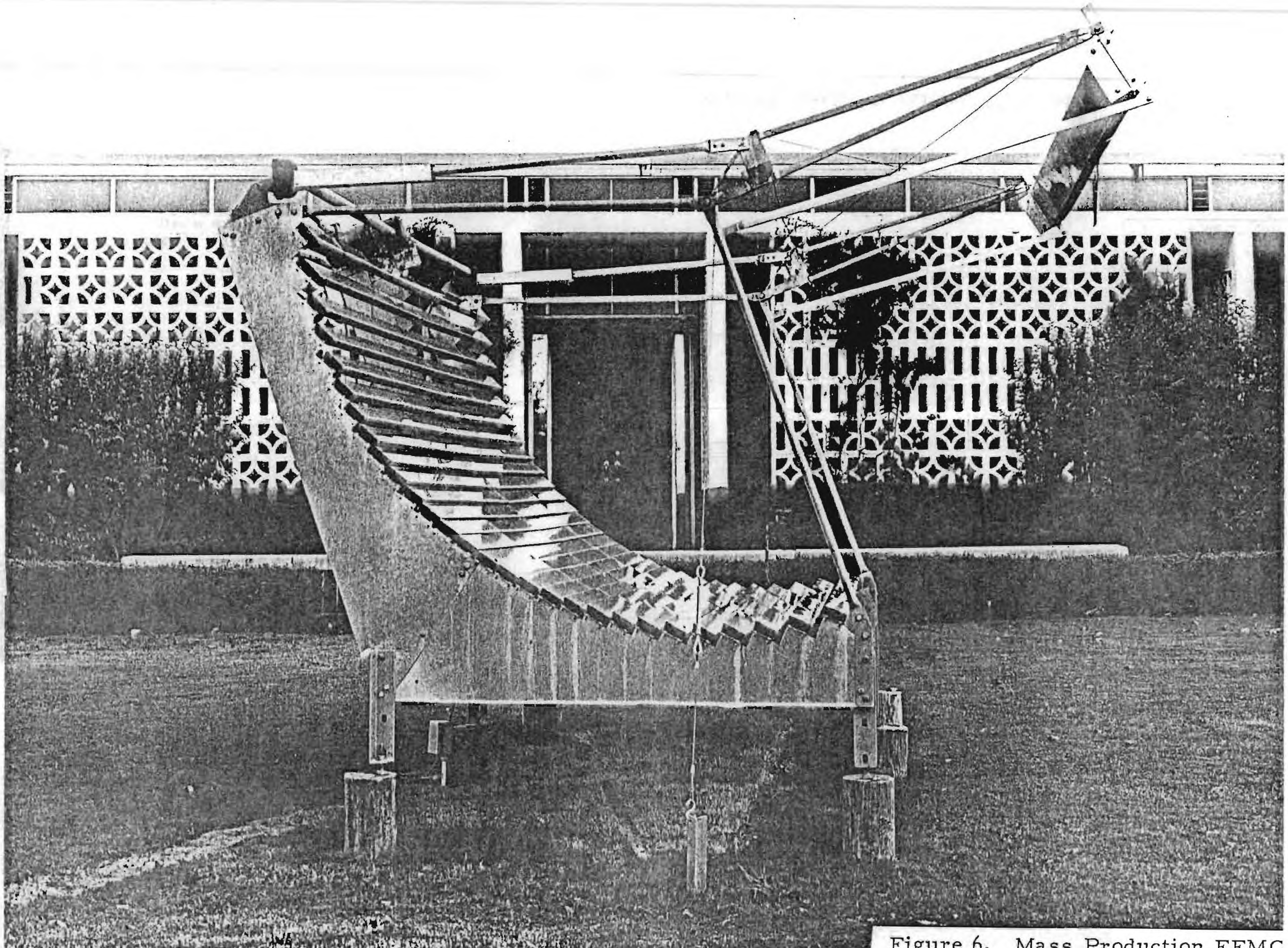
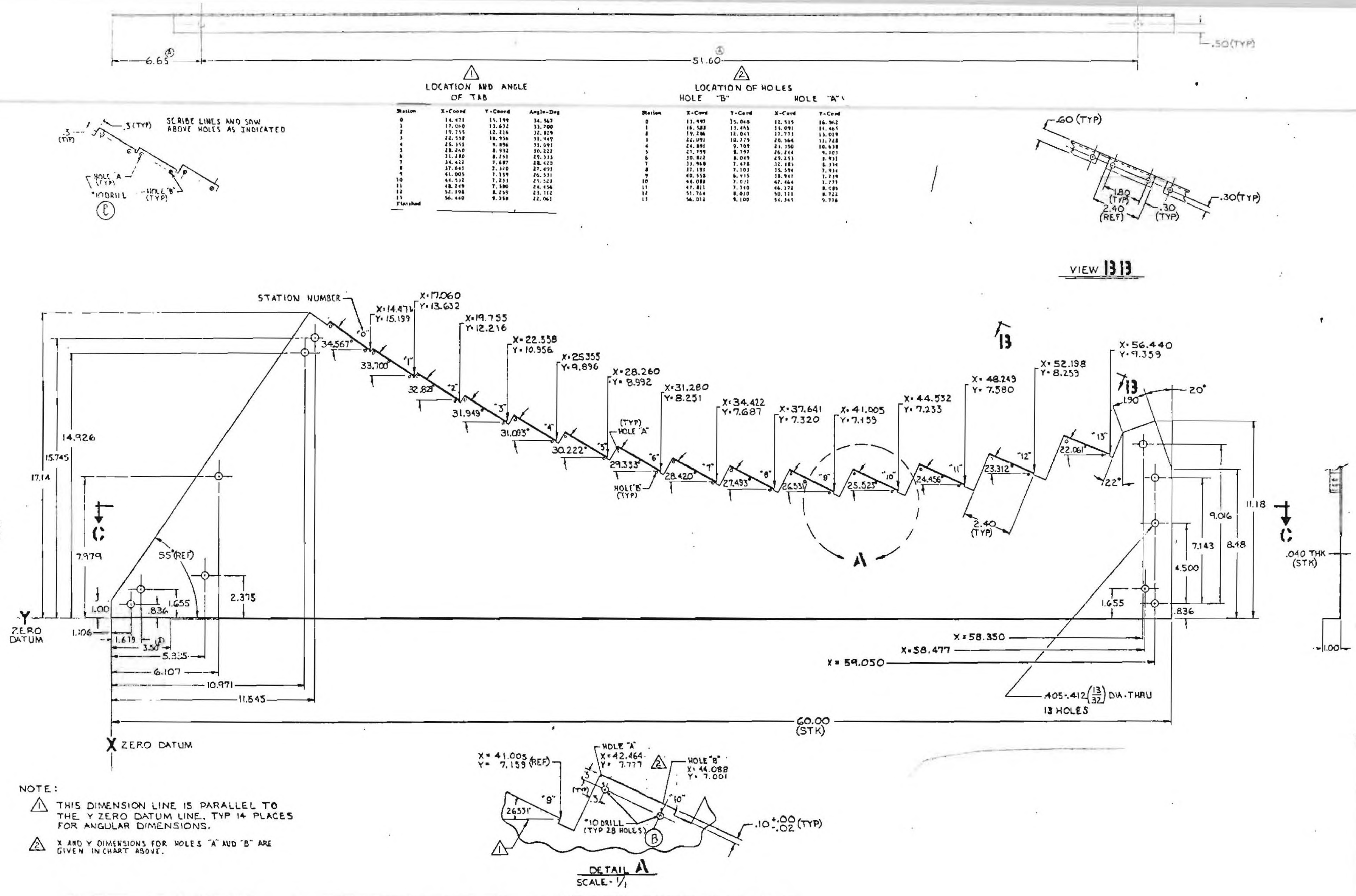


Figure 6. Mass Production FFMC Module



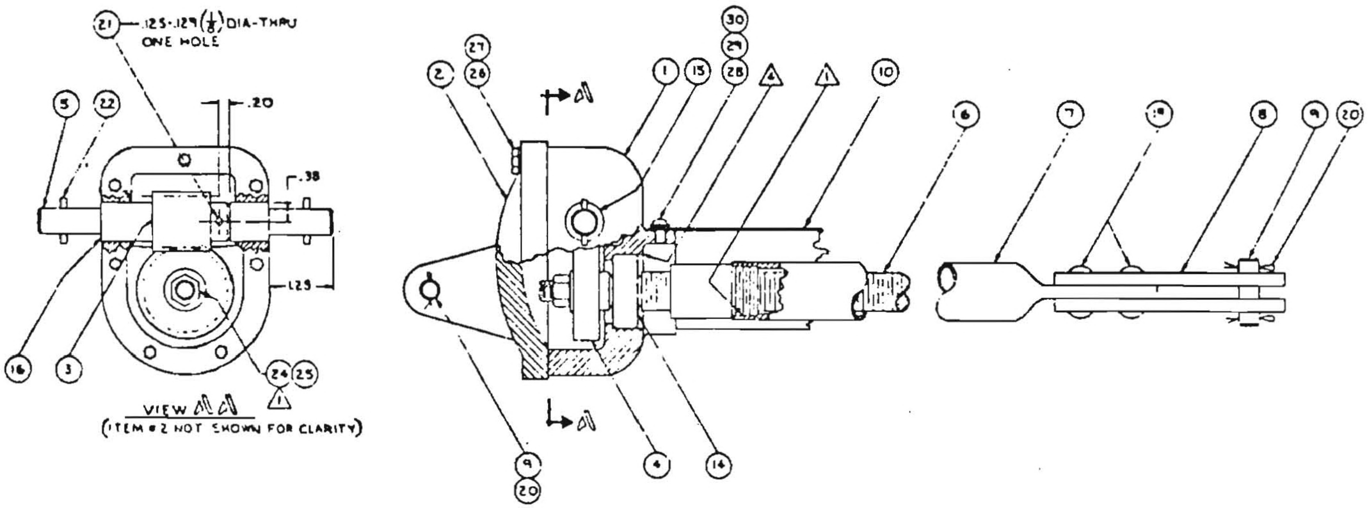
LOCATION AND ANGLE OF TAB

Station	X-Coord	Y-Coord	Angle-Deg
0	14.471	15.199	34.567
1	17.060	13.632	33.700
2	19.755	12.216	32.829
3	22.558	10.956	31.949
4	25.355	9.896	31.093
5	28.260	8.992	30.222
6	31.280	8.251	29.333
7	34.422	7.687	28.420
8	37.641	7.320	27.493
9	41.005	7.159	26.531
10	44.532	7.233	25.523
11	48.249	7.580	24.456
12	52.198	8.259	23.312
13	56.440	9.358	22.061
Finished			

LOCATION OF HOLES

	HOLE "B"		HOLE "A"	
Station	X-Cord	Y-Cord	X-Cord	Y-Cord
0	13.997	15.048	12.515	16.562
1	16.583	13.466	15.091	14.465
2	19.286	12.043	17.773	13.019
3	22.091	10.775	20.564	11.728
4	24.891	9.709	23.350	10.638
5	27.799	8.797	26.244	9.303
6	30.822	8.049	29.253	8.931
7	33.968	7.478	32.185	8.334
8	37.191	7.103	35.594	7.934
9	40.558	6.915	38.967	7.739
10	44.088	7.001	42.464	7.777
11	47.811	7.340	46.173	8.085
12	51.724	8.010	50.131	8.722
13	56.012	9.100	54.343	9.776

Figure 8. Channel Support Bulkhead



NOTE:

1. APPLY LOCTITE (S-A PART NO. 64819) TO INDICATED THREADS AT ASSY.
2) MATING SURFACES OF ITEMS 1 & 2 TO BE CLEANED AND GREASED.
3) CLEAN ITEMS 3, 4 & 14 AND COAT WITH TEXACO LOW-TEMP "EP" PER MIL-G-23827 OR EQUIVALENT.
4. DEFORM THIS EDGE OVER BEARING (ITEM NO. 14) IN 5 PLACES AROUND OPENING TO CLAMP BEARING (ITEM NO. 14) IN PLACE.

Figure 10. Details of Receiver Drive Actuator

The mirror positioning and support system is designed so the individual parts can be fabricated with efficient machinery having high production output rates. The resulting parts need no secondary operations or hand work. Each mirror is attached to the support channel with two small steel clips. Since mirror installation is a field operation, the mirror hold-down clips are designed so they can be installed by hand. The structural stringers and diagonal braces are made from standard gage steel tube that is flattened on the ends and pierced as shown in Figure 12.

Each 10-foot module has a single support arm to position and support the energy collecting receiver subassembly. The support arm is driven to the proper angle by a crank-arm type linear actuator consisting of a high efficiency ball screw jack. The drive and mounting devices for the linear actuator are designed and fabricated for this particular application to match the hardware to the requirements of the system, thus eliminating excess parts and unnecessary expense.

Complete assembly views are shown in Figures 13 (end view), 14 (rear view), and 15 (front view). Cross bracing and cables for rigidity can be seen in these views.

The materials required for this concentrator design including receiver are as follows:

	kg/m^2
Steel	25.9
Aluminum	2.0
Glass	9.8
Insulation	0.7

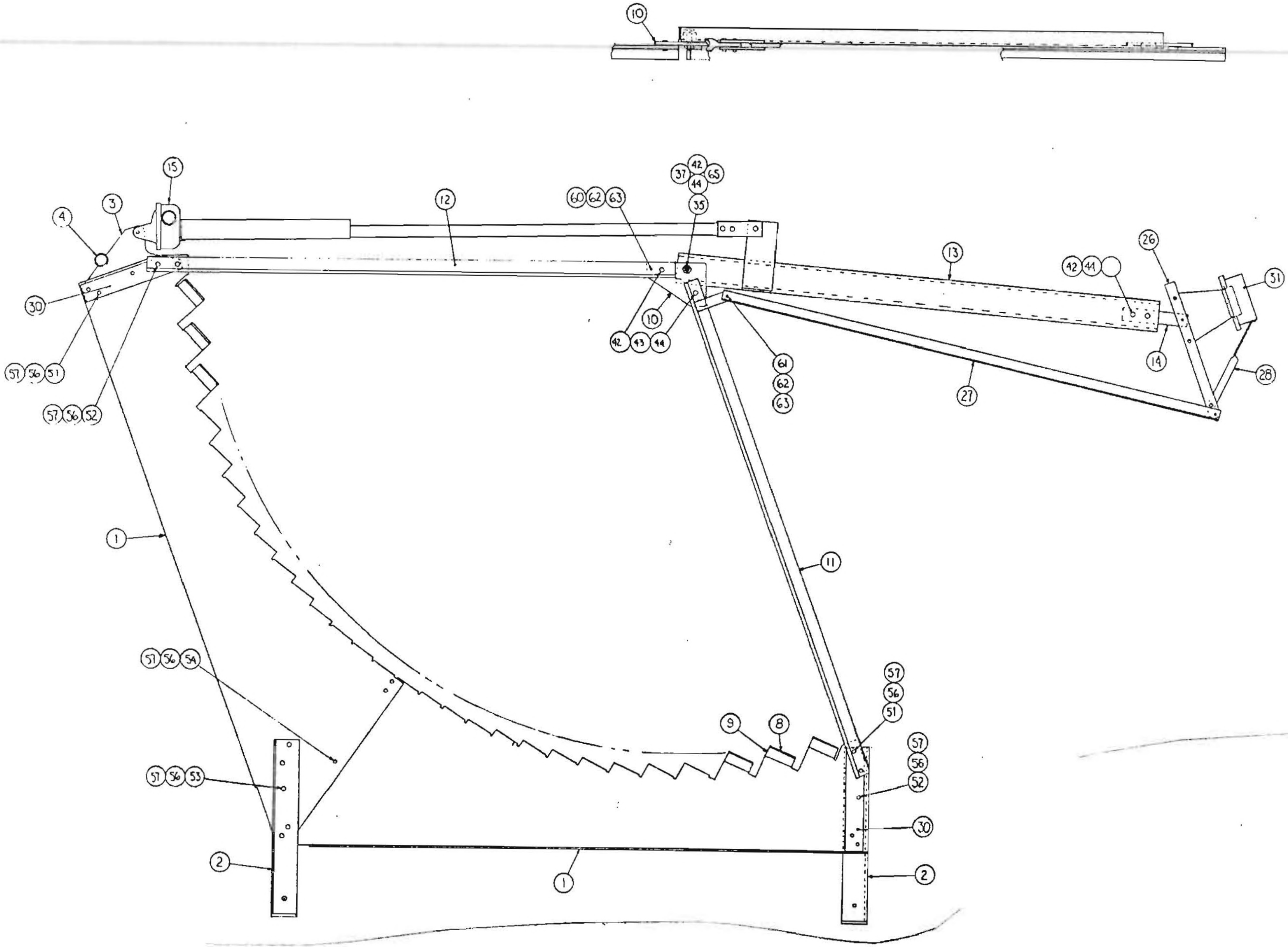


Figure 13. FFMC End Assembly View

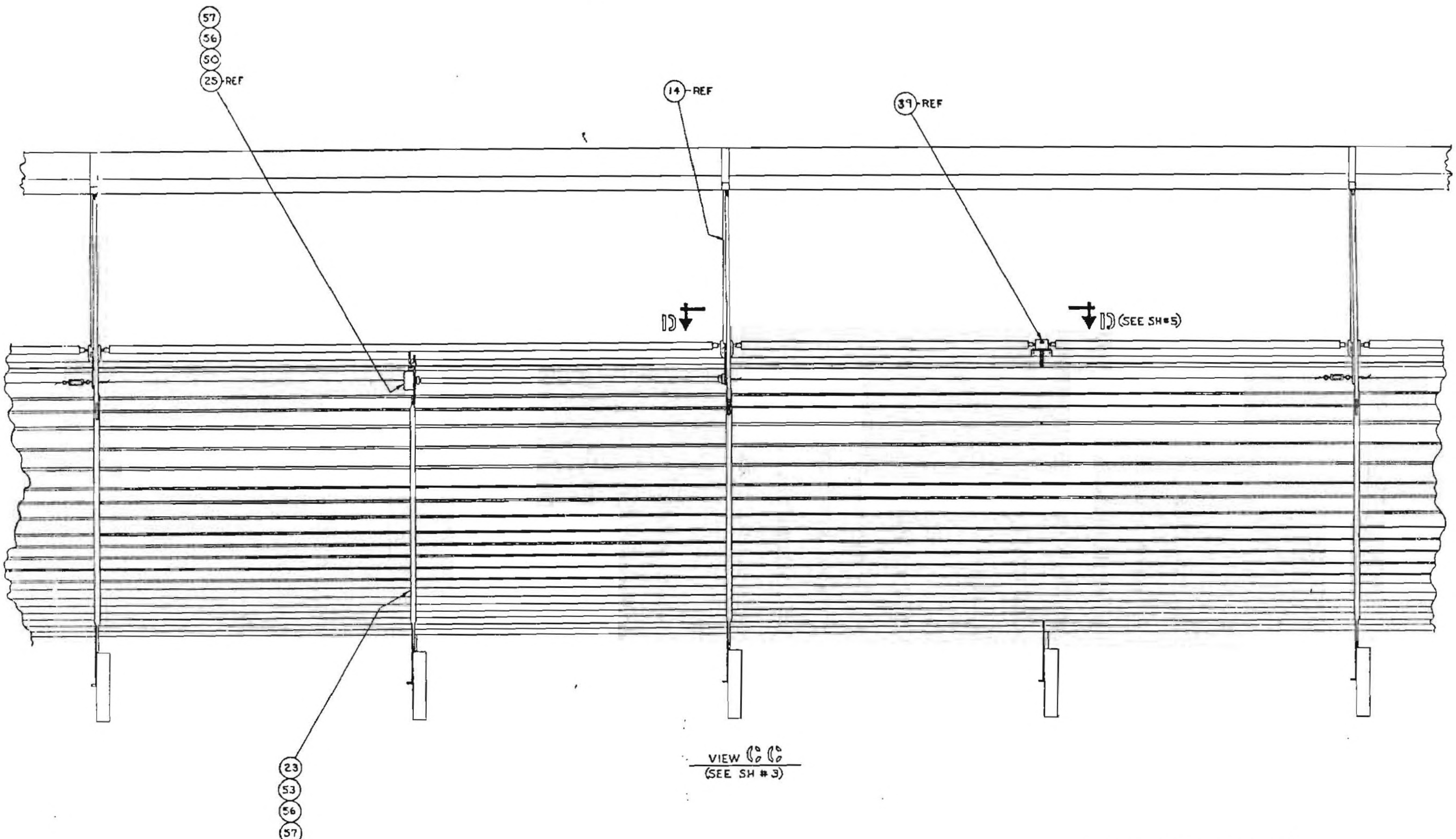


Figure 15. Front FFMC Assembly View

moves the receiver arm, and the fourth is the master tracker which tracks the sun and controls the receiver drives. There is one receiver driver per 130 ft of array length (867 ft^2) and one master tracker per installation. The reason for the necessity for one receiver arm drive for every 130 ft of array is due to the fact this requires a drive shaft 65 ft in length running through 7 drive jacks and 14 couplings. This produces additive drive errors which reaches a limiting error bound.

A breakdown of the collector costs is shown in Table I. Scientific-Atlanta salary rates, overhead rates, and expense and interest have been used. A reasonable company profit of 15% (7-1/2% after tax) has also been taken.

Assuming a 100,000 ft^2 installation which requires 115 arrays (130 ft x 6.7 ft), the following costs result from Table II.

Production Rate - 100,000 ft^2/yr

Qty	Component	FOB Price
115	Reflector Arrays (130 x 6.7)	$ 851,115
115	Receivers - 130 ft	208,725
115	Receiver Drives	94,875
1	Master Sun Tracker	1,140
	Total	$1,155,855
	FOB Cost/ft^2	$11.56/$ft^2$

Installation Costs

Installation costs were divided into two categories: site preparation and erection. Site preparation included grading, pouring of 2 concrete posts for every 5 ft of collector length and graveling the site to prevent vegetation growth and dust. This latter element is felt necessary for minimum maintenance. Erection costs were then to erect the collectors onto the concrete posts with one fixed inlet and outlet provided per 130 ft of array length. The general contractor's personnel will carry out the site preparation and all erection except the fitting of the receiver to the tracking arm which contains the fluid piping. This will therefore be carried out by the mechanical contractor. The quotes were as follows:

30,000 ft^2 FFMC Installation	
Site Preparation	\$24,600
Erection	35,100
Total	\$59,700
Installation/ft^2	\$1.99

Operating Cost

The operating costs were broken down into the following categories:

1. Mirror Washing Manpower
2. Mechanical & Electrical Maintenance
   a) Manpower Cost
   b) Material Cost
3. Utilities
   a) Water
   b) Electricity

The mirror washing manpower was estimated at 4000 ft^2 per hour by using city water pressure washing which Sandia Laboratories found to be the best method of cleaning mirrors retaining their reflectivity to near original value.

Table III

FEATURE LIST (a)
QUANTIFIABLES

1. Cost Items

1.1 Prototype collector/receiver module materials per m^2 of collector aperture area.

Material	Amount (kg/m^2)	Cost ($\$/m^2$)
Concrete	28.8	\$ 0.36
Steel	25.9	18.90
Glass	9.8	5.91
Aluminum	2.0	3.80
Insulation	0.7	2.15

1.2 Total collector/receiver module weight (kg/m^2 of collector aperture area) 66.5

1.3 Prototype collector/receiver module labor cost (Man-hr/m^2 of collector aperture area) 10^2 m^2

6.5 skilled

---- unskilled

1.4 Massproduced collector/receiver module construction labor cost (man-hr/m^2 of collector aperture area) 10^4 m^2/installation

---- skilled

1.2 unskilled

1.5 Massproduced collector/receiver module factory labor cost (man-hr/m^2 of collector aperture area)

2.7 skilled

--- unskilled

2. Performance Items

2.1 Optical efficiency, E_o ($0 < E_o < 1$)

Component	Net Reflectance	Net Transmittance
Collector	R_c = 0.88	T_c = 1.0
Receiver	R_r = 0.92	T_r = 0.90

$$E_o = R_c \cdot T_c \cdot R_r \cdot T_r = 0.73$$

Table III (continued)

FEATURE LIST (b)
Descriptives

1. Collector Specifications

1.1 Module Size (Collector Aperture), 2 m x 3 m increments

1.2 Geometry; 28 fixed east-west rear silvered mirror slats (7.3 cm wide each) spaced over 105° of a 127 cm radius arc such that the focal line is on a east-west linear band which moves north-south but is always located on a 127 cm radius arc in front of the mirror. The receiver is single glazed with insulated back and sides.

1.3 Type (check one)

	Geometrical	Fresnel
Reflective	✓	
Refractive		

1.4 Tracking (check one)

None X, Fixed Tilt Angle Latitude °, Direction To Equator

Seasonal ___ / Diurnal ___ { One Axis ___, Fixed Tilt Angle ___ ° / Two Axis ___ }

Other ___ (Describe)

List the components that move during tracking.

receiver, ___, ___, and ___.

2. Receiver Specifications

2.1 Absorptivity of absorbing surface, α = 0.92 $(0 < \alpha < 1)$

2.2 Emittance of absorbing surface, ϵ = 0.2 $(0 < \epsilon < 1)$

@ T = 315 °C

2.3 Heat Transfer Fluid, Therminol 66 or Water.

2.4 Design Fluid Outlet Temperature, 315 °C.

Table IV

Concentrator Cost Comparisons - 1,000,000 ft^2/yr

		General Atomic	MDAL	Raytheon	Sheldahl	Parabolic Cylinder	Scientific-Atlanta
1.	Installation Size (ft^2)	2800	2046	1140	2800	≈ 2500	≈ 2800
2.	Installed Collector ($/$ft^2$)[6] (Excluding external plumbing & electrical wiring)	$12.80	$21.00[1]	$14.72	$15.39	$15.80[2]	$9.59[3]
3.	20 year Operating Cost ($/$ft^2$)	16	24	24	16	18.50	23
4.	Material Cost ($/$ft^2$)	5.58[5]	15.49[5]	9.80[5]	7.17[5]	N/Available	2.69[4]
5.	Weight (#/ft^2)	91.4	28.4	74	22.5	N/Available	18.9[7]
6.	Reflectivity/Transmittance	.92	.84	.92	.82	.92	.92
7.	Concentrator Eff. (%)	67	71	87	68	85	67
8.	Receiver Eff. (%)	75	70	93	79	70	81
9.	Net Energy (winter) (KJ/ft^2-day)	783.7	937.8	1161.2	806.3	1156.	1080
10.	Net Energy (summer)	948.7	1259.7	2007.6	1033.7	1423	1121
11.	Figure of Merit (winter)[6] ($/KJ-day)	0.037	0.048	0.038	0.039	0.030	0.0089
12.	Figure of Merit (summer)[6] ($/KJ-day)	0.030	0.036	0.019	0.030	0.024	0.0086

Notes:
1. $25/$ft^2$ including plumbing. $4/$ft^2$ plumbing cost assumed.
2. $18.50/$ft^2$ including plumbing. $2.70/$ft^2$ plumbing cost assumed.
3. Extrapolated from "hard" 100,000 ft^2/yr production costs.
4. Assumes raw material only; $0.30/# steel cost, $0.40/# glass cost, $0.50/# al cost, $0.01/# conc cost.
5. Exact method of calculation unknown.
6. No field plumbing or electrical cost for field interconnection.
7. Includes concrete mounting pads. Excluding concrete 7.49#/ft^2.

5. Proposed Sun Tracking System

A block diagram of the improved sun-tracking system is shown in Figure 16. This system comprises two principal functional subassemblies:

(1) Solar position detector and buffer circuit.

(2) The DC drive and position serro for each FFMC.

The solar position detector is portrayed in Figure 17. A pair of balanced solar cells, interconnected electrically, are mounted on either side of a pivoting plate. Under solar radiation a certain voltage is generated in each cell. Unless the pivot plate lies in the solar plane, an unbalanced signal is generated by the cells. In response to an unbalanced signal, the variable reluctance motor is energized by the comparator circuit to drive the plate into alignment with the sun to null the signal from the solar cells. This arrangement allows for a single pair of cells to provide both coarse and fine tracking capability. The comparator circuit will be provided with sufficient delay and dead-band to eliminate oscillation or chatter without inducing excessive error in tracking.

Once the position detector registers on the sun, the shaft position potentiometer signal accurately represents the solar altitude. This signal is processed in the buffer circuit to yield a signal corresponding to the position required of the receiver assembly. Each FFMC in the array is provided with a simple closed loop controller. The reference for this control is the buffer output, and the error signal is the difference between this signal and the output of a shaft potentiometer mounted at the pivot point of the receiver arm. If the error is sufficient, the comparator circuit actuates the individual drive motor of the FFMC. By means of the line shaft and linear actuators, the receiver is moved to the correct location which nulls the error.

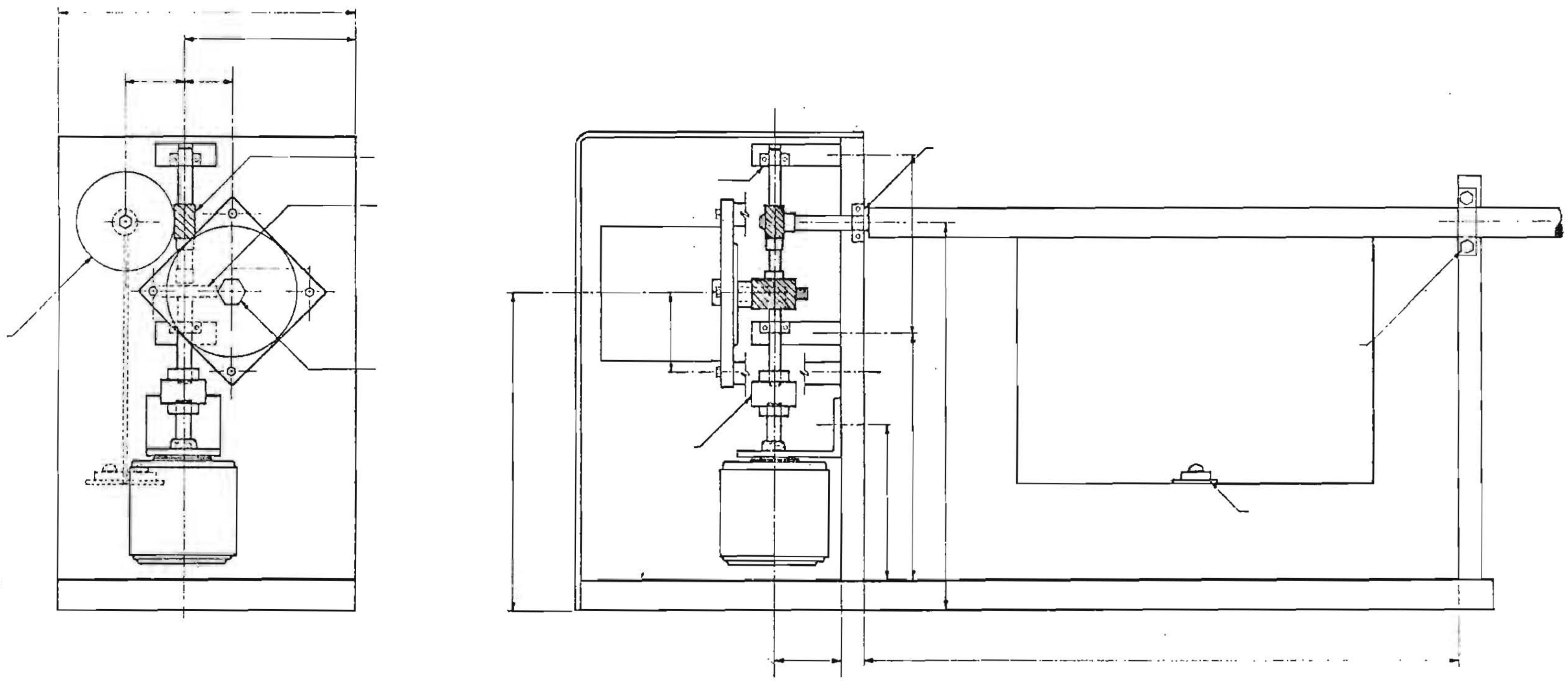


Figure 17. Sun Position Detector

Predicted Daily Performance

The performance of the FFMC has been predicted for both Albuquerque, New Mexico and Fort Hood, Texas. Performance figures are based on average summer and winter clear day radiation for both cities.

Tables V and VI give the total energy collected per ft^2 as a function of solar time of day and fluid temperature for both an east-west configuration and a north-south configuration.

East-west means that the axis of the FFMC reference cylinder lies in one of the earth's latitudinal planes. North-south means that the axis lies in one of the earth's longitudinal planes.

The east-west FFMC configuration collects slightly more energy than the north-south configuration and the piping and structure costs are considerably less. Therefore, when comparing the east-west FFMC strictly to the north-south FFMC, the east-west configuration has a distinct economic advantage. In the performance calculations the aperture heat loss from the FFMC receiver was based on experimental heat loss data collected in the laboratory tests discussed in this report.

For an east-west orientation, the total heat collected is given by

$$\dot{Q}_C = 0.67\ I_D \cos\left(90° - \phi - \theta_T\right)$$

$$- \frac{T_R^4 - T_{amb}^4}{1.51 \times 10^{11}}$$

$$- .047\ (T_R - T_{amb})$$

Scientific-Atlanta, Inc.
Fixed Faceted Mirror Concentrator

Energy Collected at Albuquerque, N. M. (Btu/hr-ft^2)

North-South Orientation Tilted South 35°

		Fluid Outlet Temperature (100°F Fluid ΔT)			
Solar Time	Direct Normal Winter/Summer	450°F Winter/Summer	500°F Winter/Summer	550°F Winter/Summer	600°F Winter/Summer
7:00	---/246	---/---	---/---	---/---	---/---
8:00	214/273	11/24	8/20	4/17	1/13
9:00	270/286	61/69	58/66	54/63	51/59
10:00	295/293	113/118	110/115	107/111	103/107
11:00	306/293	154/158	151/155	148/151	144/148
12:00	309/293	169/162	165/159	162/156	158/152
13:00	304/293	153/150	150/147	147/143	143/140
14:00	290/285	111/114	108/111	104/107	101/104
15:00	262/274	59/66	55/63	52/59	48/56
16:00	209/251	10/20	7/17	4/13	---/10
17:00	---/206	---/---	---/---	---/---	---/---
Daily Totals	2459/2993	841/881	812/853	782/820	749/789

East-West Orientation Tilted South 35°

Solar Time	Direct Normal Winter/Summer	450°F Winter/Summer	500°F Winter/Summer	550°F Winter/Summer	600°F Winter/Summer
7:00	---/246	---/2	---/---	---/---	---/---
8:00	214/273	28/45	25/42	21/39	18/35
9:00	270/286	78/88	75/85	72/81	68/78
10:00	295/293	118/122	114/119	111/116	107/112
11:00	306/293	145/141	141/138	138/135	134/131
12:00	309/293	153/148	150/144	146/141	143/137
13:00	304/293	144/141	140/138	137/135	133/131
14:00	290/285	115/119	112/115	109/112	105/108
15:00	262/274	75/84	72/80	69/77	65/73
16:00	209/251	27/40	24/37	20/33	16/30
17:00	---/206	---/17	---/---	---/---	---/---
Daily Totals	2459/2993	883/947	853/898	823/869	789/835

Table V. **Energy Collection Calculations for Albuquerque, N. M.**

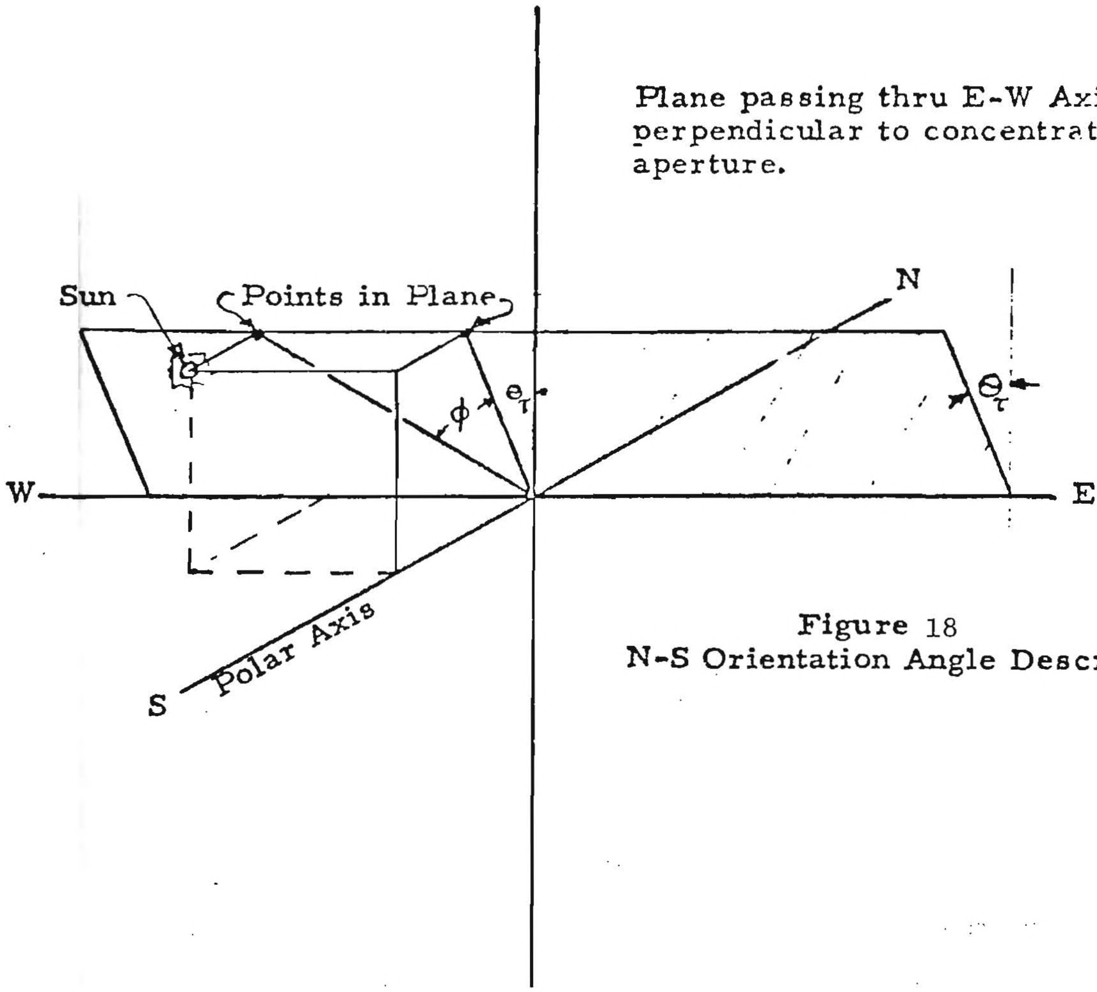


Figure 18
N-S Orientation Angle Description

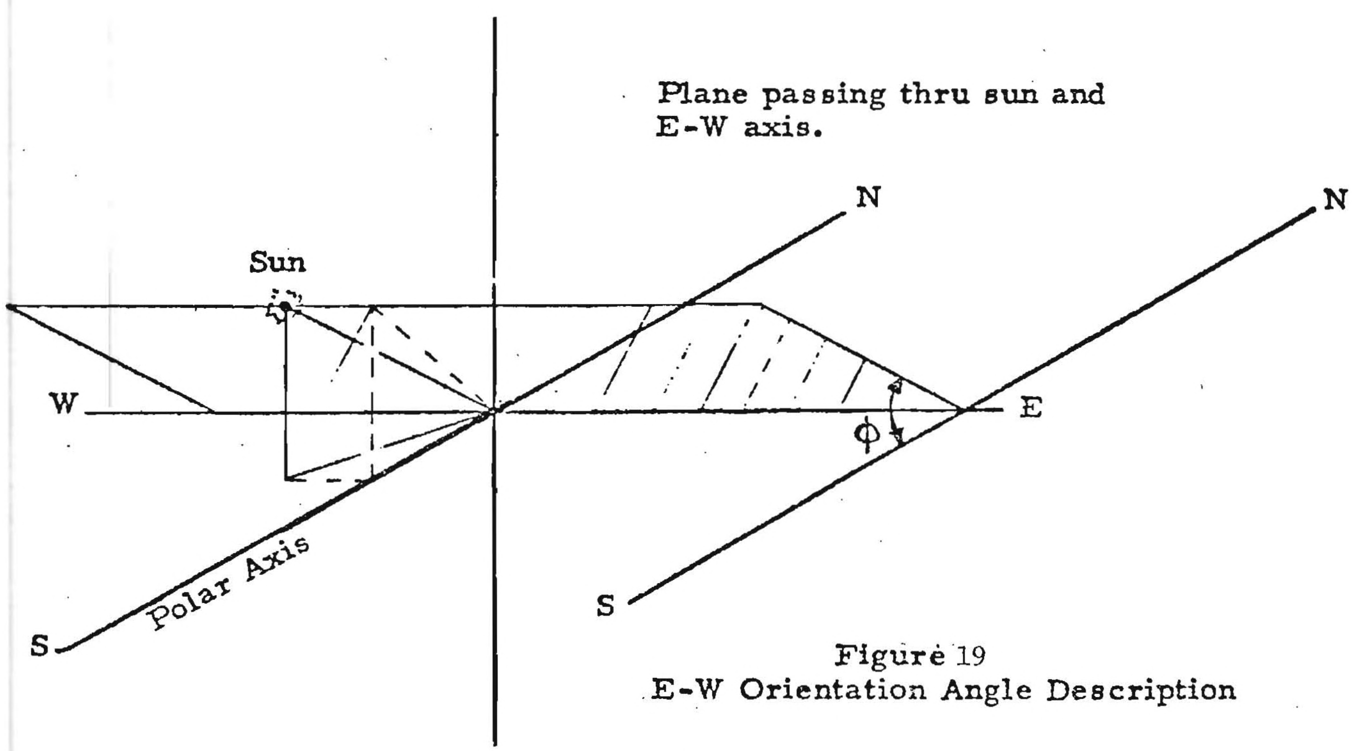


Figure 19
E-W Orientation Angle Description

References

1. Russel, J. L., Jr., DePlomb, E. P., and Bansal, R. K., "Principles of the Fixed Mirror Solar Concentrator," General Atomic Report GA-A12902, April, 1974, (submitted to Solar Energy).

2. Williams, J. R. and Hutchins, S. F., "Development of a 540 ft^2 Prototype Faceted Fixed Mirror Solar Concentrator," Report No. 759032, IECEC Record, 1975.

3. Williams, J. R. and Hutchins, S. F., "Development of a Solar Heat Supply System with Fixed Mirror Concentrators," Proposal for a continuation of NSF Grant GI-43936, January 21, 1975.

4. Bansal, R. K., "Theoretical Analysis of Fixed Mirror Solar Concentrator," M. S. Thesis, School of Engineering, Arizona State University, May 1974.

5. Steward, W. G., "A Concentrating Solar Energy System Employing a Stationary Spherical Mirror and Movable Collector," Proceedings of the NSF/RANN Solar Heating and Cooling of Buildings Workshop, NSF/RANN-73-004, pp. 17-20, July 1973.

6. Kreider, Jan, "Modeling and Construction of the Stationary Reflector/ Tracking Absorber Solar Concentrator," presented at the NSF/RANN Workshop on Solar Collectors for Heating and Cooling of Buildings, New York, N. Y., November 1974.

7. Barr, Erwin, "Cost Effective Focusing Collector for Solar Heating and Cooling," Presented at the NSF/RANN Workshop on Solar Collectors for Heating and Cooling of Buildings, New York, N. Y., November 1974.

8. Hottel, H. C. and Woertz, B. B., Transactions of the ASME 14, 91 (1942), "Performance of Flat-Plate Solar-Heat Exchangers."

9. Aynom., Product Brochure, "Solector Solar Energy Collector", Sunworks, Inc., 1976.

10. Rollins, J. F., "Design, Construction and Evaluation of a Fixed-Mirror Solar Concentrator," M.S. Thesis, Georgia Institute of Technology, September, 1974.

11. Damshala, P. R., "Theoretical Analysis of Heat Exchangers for Fixed Faceted Mirror Concentrators," Ph. D. Thesis, Georgia Institute of Technology, 1976.